The distance between stations A and B is 2,800 m., which on the plotting board is as indicated on figure 1 (the scale on the original being 1 cm. to 200 m.). The method of finding horizontal distances, altitude, wind directions, and velocities is as follows:

Set the celluloid protractor with 0° on station B. Set movable arm at 310°. From B follow line on azimuth 190°. Where the 190° line meets the protractor arm, place point 1. The distance of point 1 from A is shown by the scale on the arm to be 550 m. Set movable arm at 20° on the vertical quadrant CD (as now placed). Follow horizontal line from 550 on scale AC to arm. The altitude, which is measured by the distance on this horizontal line, is shown by the scale to be 200 m. The same method of finding horizontal distances and altitudes applies to all other minutes. To find wind direction at the end of the first minute move the celluloid protractor so that A and point 2 are on the same vertical line, and read wind direction at C from the celluloid protractor. For the end of the second minute set points 1 and 3 on the same vertical line, and read direction at C. To find the velocity at the end of the first minute measure from A to point 2. The distance A to 2 is 63 mm. on the full-sized plotting board; 63 mm. is equivalent to 1,260 m., the distance traveled in 120 sec., or at a rate of 10.5 m./s. The same result would have been obtained by dividing 63 by 6. For the velocity at the end of the second minute measure from 1 to 3, and divide by 6. The same method applies to all minutes following. Obviously, if the direction is changing from minute to minute, the velocities so computed will be somewhat too small. In practice, however, the results are sufficiently accurate, considering other sources of error.

SOME OBSERVED IRREGULAR VERTICAL MOVEMENTS OF PILOT BALLOONS.

By Lieut. I. R. TANNEHILL, Signal Corps, Meteorological Service.

[Dated: Fort Hancock, N. J., May 30, 1919.]

In a quiet atmosphere the rate of ascent of a pilot balloon does not differ materially from that computed from formula. For ordinary purposes it is a constant rate.[1] When there is active convection, however, there may be irregularities in the rate of ascent and the average vertical movement of the balloon may differ widely from that assumed. These variations from the computed rate are due, undoubtedly, to vertical movements of the air and may be taken as a measure of upward and downward components of wind movements.†

When there are ascending air columns, there must be rotary movements in many cases,* but these whirls do not appear in the horizontal projection of the balloon's path, for this path shows only the movement of the balloon with reference to a point on the earth's surface and the rotary motion would be such with reference only to the air in the stratum in which the balloon drifts. If there were a whirl under a cloud, the balloon would move in a spiral with reference to the cloud but not with reference to a point on the earth's surface, unless the cloud be stationary. A flight giving a wavy projection was replotted with reference to the air, by subtracting the average wind movement (in both magnitude and direction) from each balloon minute's movement. The result was a circular path, as expected. It seems that when the balloon is rising at rates greater than that computed such unusual motion is evidenced by a wavy projection.

The whirls which appear in the horizontal projections of the paths of pilot balloons seem to be whirls in another sense.[2] In these cases there seems to be a straight wind at any level, yet the balloon moves in a spiral course because it rises through strata with various wind movements. It does not seem likely from a study of such cases that the balloon would move in a whirl if it did not rise.

For these reasons—(1) that the balloon rises in a quiet atmosphere at a rate which is nearly constant and (2) that although convectional movements of the air may be typically rotary, the balloon does not necessarily (and probably rarely does) move in a spiral with reference to a point on the earth's surface—it seems safe to use the irregularities in the rate of ascent of pilot balloons as an indication of vertical air movements.

It is the object of this paper, then, to discuss briefly the irregularities that are observed in the ascensional rate of pilot balloons, particularly beneath clouds, as indicating vertical movements of the air.

As to unusual differences, the following is an illustration: On June 13, 1918, at 1:20 p. m., at Fort Monroe, Va., a pilot balloon with an ascensional rate of 193 meters per minute from formula[3] was observed with two theodolites to rise at an average rate of 396 meters per minute for five minutes before passing into a cumulus cloud. This occurred with a fresh northwest wind, temperature 23° C., and pressure 756 mm. In Table 1, the rate of ascent of this balloon is compared with others launched on June 12 and 13, 1918, at Fort Monroe.

TABLE 1.—*Heights of pilot balloons observed with two theodolites at Fort Monroe, Va., June 12 and 13, 1918.*

Date.	Time.	1	2	3	4	5	6	7	8	9	a	b
June 12, 1918	1:05 p. m.	200	440	700	920	1,195	1,430	1,680	.....	.....	187	240
June 13, 1918	8:25 a. m.	150	400	760	930	1,170	1,270	1,510	.....	.....	172	216
June 13, 1918	9:38 a. m.	.....	520	800	1,030	1,220	1,520	1,750	1,960	2,150	196	239
June 13, 1918	1:20 p. m.	420	850	1,250	1,670	1,980	.....	.....	.....	.....	193	396
June 13, 1918	2:30 p. m.	270	350	520	600	725	855	1,105	1,375	1,650	.....	.....

In columns headed 1, 2, 3, etc., is shown the height of the balloon at the end of each minute. Column headed "a" gives the computed rate from formula and column headed "b" gives the actual average rate taken from the height of the balloon at time of last reading with both theodolites. Heights are in meters and rates of ascent in meters per minute.

It is apparent from an inspection of this table that there were local strong vertical movements during the afternoon of the 12th and the day of the 13th. Therefore, this phenomenal rate of ascent of one pilot balloon (396 meters per minute) was evidently due to atmospheric conditions. At 2:30 p. m., the same day, one hour and ten minutes later, a balloon was launched which rose very irregularly, as shown in the table. During the second and

[1] See pp. 211–212, above.

**Dust whirls at times become cloud-capped; also the whole base of a large cumulus has been seen to rotate slowly.*—C. F. B.

†This explanation may not be applicable to those irregularities observed when local vertical currents may not be present. Thus, R. Wenger (Ann. d. Hydr. u. Mar. Met., 1917, vol. 45, pp. 121–137), after considering the air resistance of spheres in air of varying degrees of turbulence and the observed variation in the rates of balloon ascents, concludes that "*The changes in the conditions of turbulence of the atmosphere explain qualitatively and quantitatively all variations which are observed in the ascensional rates of balloons,*" and that "It is not possible, from the variations of ascentional rate to come to any conclusions as to the vertical movements in the atmosphere."—C. F. B.

[2] See MONTHLY WEATHER REVIEW, Dec., 1918, 46: p. 553.

[3] See pp. 211 and 218, above.

fourth minutes this balloon rose only 80 meters, while during the ninth minute it rose 275 meters.

Cases in which balloons have moved upward much faster than expected are common, but an attempt by the writer to classify a number of these according to the kind of cloud in which the balloon disappeared did not give consistent results. It is, therefore, advisable to cite a few cases and show what may happen under such circumstances.

Since it appeared likely that topography affects the ascensional rate of a balloon during the first few minutes of flight experiments were made to determine the extent of this influence.

On May 12, 1919, at Fort Monroe, Va., two pilot balloons were filled, partly with air, partly with gas, so that the free lift was exactly zero and the balloons when released, with care, remained stationary. They were tested in a room the temperature of which was practically that outside. There was at the time a layer of strato-cumulus covering the entire sky. The temperature was 14.5° C., the pressure 759.9 mm., and the wind north, 4. 4 m./s.

The first of these balloons was released from the rampart at 1:50 p. m., and during practically the entire time of flight it drifted over the bay. It was assumed that the balloon's horizontal motion was that of the air, 4.4 m./s. From the distances by this assumption the altitudes were computed from elevation angle readings with one theodolite. This balloon rose irregularly to a height of 127 meters (from this assumption) on the 13th minute. It then descended slowly to 120 meters at the end of 16 minutes.

Balloon No. 2, released immediately afterwards, with a wind of 4.2 meters per second, rose (on a similar assumption) to a height of 694 meters on the 18th minute and then descended to 583 meters when lost at the end of the 21st minute.

This north wind, coming from the water, was probably thrown upward in passing over the ramparts. Since the sky was clouded it is apparent that there was no appreciable heating effect on the balloon. These figures seem to indicate that local currents at the surface may affect the rate of ascent of a balloon during the first few minutes. Certainly, after that time, the influence of clouds in some cases may be marked. The errors which might arise in an assumption of a uniform ascensional rate from formula are obvious.

It has been shown that the actual rate of ascent may in some cases depart materially from that calculated from formula. What effect does such a departure have upon the wind aloft data secured from one-theodolite observations, assuming altitudes from formula? An individual case may be interesting.

At Park Place, Houston, Tex., January 6, 1919, the projection made from a balloon observation at 2:58 p. m., 90th meridian time, was as shown in figure 1. The ascensional rate of this balloon from formula was 182 meters per minute. There were at the time ten tenths of alto-cumulus clouds. Observations before the ascension showed the clouds to be moving from southwest by south, but from the flight it was found that the balloon was moving from the west on the 8th minute, or just before it passed into the clouds. One theodolite was used. The clouds were assumed from this observation to be 1,600 meters high.

Later, observations showed that the clouds were still moving from the same direction, southwest by south. It therefore seemed that the projection was in error. The fact that alto-cumulus clouds should be much higher seemed to indicate that the assumed altitudes were wrong. Referring to figure 1, let us assume that the balloon moved from the 7th to the 9th minutes in the direction in which the clouds moved. The locations of the balloon would have been at 8a and 9a instead of at 8 and 9. This would necessitate an ascensional rate of the balloon during the 8th minute of 400 meters per minute and during the 9th minute of 600 meters per minute. The balloon, being lost during the next minute, the actual altitude of the clouds may have been over 3,000 meters.

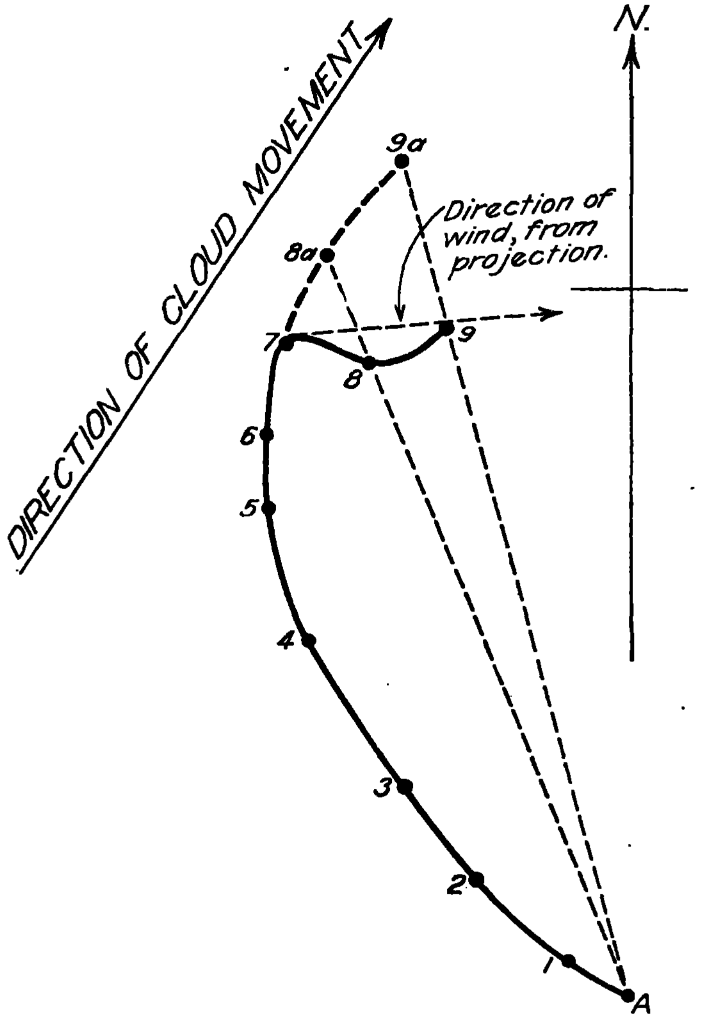

FIG. 1.—The solid line A to 9 is the path of the balloon projected upon the horizontal plane, and is from readings with one theodolite. The figures 1, 2, 3, etc., show the position of the balloon at the end of each minute. The figures 8a and 9a show probable positions of balloon at the end of the 8th and 9th minutes, from movement of clouds into which the balloon passed. From these distances, A–8a and A–9a, the corrected altitudes were computed, using the angle of elevation.

That there was such an updraft under these clouds is possible. It began to rain at 9:40 p. m.

The peculiar shape of this projection was not due to errors in observation. As a check, another balloon was launched at 3:28 p. m. and the same abrupt change in direction, using one theodolite, was shown. Errors in the assumed height, therefore, produce errors not only in distances traveled and consequently in wind speeds but produce serious errors in direction of the wind as obtained with one theodolite, provided the balloon is not moving straight away from the station.

* * * * *

In a paper by A. E. M. Geddes, published in the Quarterly Journal of the Royal Meteorological Society, April, 1915, volume 41, pp. 123–135, pilot-balloon observations at the Observatory, King's College, Aberdeen, are discussed particularly with reference to wind values aloft in relation to the gradient wind. The rates of ascent of the balloons are given, however, and tabulated according to the kind of cloud in which the balloon was lost.

In the case of strato-cumulus clouds, it is stated that for corresponding lifting powers the upward velocities were greater than on clear days. (Cf. footnote † on p. 223.) No sudden increase, however, was observed on passing into the cloud.

A sudden increase in upward velocity was observed in all cases but one where the balloon passed into cumulus clouds. In one of these flights, the balloon rose at a rate of 6.2 meters per second immediately before passing into the cumulus cloud. This gives a rate of 372 meters per minute, which is not much different from the high rate noted at Fort Monroe on June 13, 1918.

With fracto-cumulus clouds there was a sudden rise at the base of the cloud. This sudden increase was not so large as in the case of cumulus clouds.

With stratus clouds there was a fairly uniform vertical velocity with no remarkable increase on entering the cloud.

In conclusion, it is stated that "in making observations with one theodolite it consequently becomes incumbent on the observer to take note not only of the free lift of his balloon, but also to study the type of cloud into which his balloon is likely to disappear, and the tendency of the barometer, before assigning any definite vertical velocity. Even then the assumption of a uniform vertical velocity is apt to round off corners and bring the condition of the atmosphere into a more ideal state than it really is. When a considerable altitude is reached, say over 3 kilometers, surface influences will have disappeared, and the one-theodolite method may be superior to the other, seeing that the base is often small compared with the distance the balloon has traveled."

* * * * *

In many instances there is not any sudden increase in rate of ascent when the balloon passes into cumulus clouds. This does not prove, however, that such vertical movements do not exist. With two theodolites the balloon is often lost at one station two or even five minutes before it is lost in or behind the cloud at the other station. The number of cases in which the balloon actually disappears in the cloud at both stations at the same time is comparatively small. Consequently it may be that in many instances the balloon passes behind the cloud or between two clouds.

In conclusion, it may be said that inasmuch as it is often necessary to observe a balloon with only one theodolite or to continue an observation when the balloon is lost to one observer, it is necessary to make a careful inspection of clouds before concluding that the drift of the balloon as plotted represents the movement of the wind. A considerable departure of the actual from the computed rate will, with one-theodolite observations, produce a serious error in the wind data deduced.

THE WORK OF THE AEROGRAPHIC SECTION OF THE NAVY.[1]

By Lieut. Commander ALEXANDER MCADIE, U. S. N. R. F., Senior Aerographic Officer.

[Dated: Harvard University, Blue Hill Observatory, Readville, Mass., Mar. 27, 1919.]

Early in January, 1918, the Assistant Secretary of the Navy asked Prof. McAdie to supervise the organization of an aerographic section in the Navy. Enrolling as lieutenant commander in the Reserve Force, this officer reported to Capt. N. E. Irwin, United States Navy, Director Naval Aviation Operations. He sailed for Europe early in April, accompanied by eight aerographic officers to take over certain observations in the British Isles and France.

Instruction in meteorology had been given in a general way at a number of naval air stations, but definite work in aerography,[2] similar to that carried on at British, French, and Italian air schools, may be said to have had its beginning on December 3, 1917, when the first group of students who had finished the course in the Ground School at the Institute of Technology, reported at Blue Hill Observatory for an intensive course of instruction in aerography. To aid in the rapid establishment of the service, Lieut. W. F. Reed, jr., also gave considerable practical and theoretical instruction at Pelham Bay, N. Y., during January, February, and March, 1918. A knowledge of the structure of the atmosphere, the relation of wind and pressure, the variation of wind with height, eddy motion, turbulence in relation to gustiness, the use of sounding and pilot balloons, forecasting for aviators at foreign and home stations, and some familiarity with the work of modern investigators—Dines, Shaw, Rotch, Gold, Cave, Taylor, and others—were regarded as necessary. As the instrumental equipment of the observatory includes many European instruments not found elsewhere in this country, students had opportunity to familiarize themselves with such instruments. The work was upon a postgraduate basis and the men entering were required to hold university degrees or possess a training equivalent to that required for a degree at the Massachusetts Institute of Technology. In all 56 men took the course. These (with the exception of four) received their commissions as ensigns. Twenty-eight American universities or colleges were represented. Of the whole number 22 had foreign service.

Through the courtesy of the British Admiralty, officers upon their arrival in Europe were permitted to spend two weeks at selected air stations, and thus get in touch with latest developments.

The British Admiralty also kindly agreed to furnish 20 complete outfits for aerographic observatories (see Fig. 2, opposite p. 227, below).

Many of the officers were elected Fellows of the Royal Meteorological Society and while in London were made welcome at the library and offices of the society. We were also made to feel at home in the Meteorological Office and were allowed the privilege of being in the Forecast Room when work was in progress. It must be remembered that at this time all weather information was confidential. Harmonious relations were maintained with the Air Service of the Army in France. Lieut. Commander McAdie and Maj. Bowie had many conferences at the Bureau Central Météorologique, and received every courtesy from the director, Prof. A. Angot.

By this cooperation, the Navy aerographers on the coasts of Ireland, England, and France became part of

[1] Published by permission of the Secretary of the Navy.

[2] "Aerography" as here used is practically synonymous with "meteorology," except that it implies that the main emphasis of the work had to do with free-air conditions.—EDITOR.